Food portion size influences accompanying beverage selection in adults.

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INTRODUCTION

Systematic reviews indicate that individuals who consume sugar-sweetened beverages are at higher risk of weight gain (Malik, Pan, Willett, & Hu, 2013; Malik, Schulze, & Hu, 2006). Sugar-sweetened beverages are a major source of added sugar (Ervin, Kit, Carroll, & Ogden, 2012; Guthrie & Morton, 2000; Langlois & Garriguet, 2011; Lee et al., 2014) and some research has demonstrated that energy in liquid form has a weaker satiety effect than the equivalent energy in solid form (Flood-Obbagy & Rolls, 2009; Mattes, 2005; Mourao, Bressan, Campbell, & Mattes, 2007). Energy in liquid form requires less mechanical processing, spends less time passing through the gastrointestinal tract (Andrade, Greene, & Melanson, 2008; Glasbrenner, Pieramico, Brecht-Krau, Baur, & Malfertheiner, 1993; Hogenkamp, Mars, Stafleu, & de Graaf, 2010; Lavin, French, Ruxton, & Read, 2002), and often lacks sensory characteristics that alert the body to prepare for the digestion and absorption of nutrients and energy (Chambers, Ells, & Yeomans, 2013; Mars, Hogenkamp, Gosses, Stafleu, & De Graaf, 2009; Yeomans & Chambers, 2011; Zijlstra, Mars, de Wijk, Westerterp-Plantenga, & de Graaf, 2008). This body of work suggests that fluid energy is not completely compensated for. Therefore, individuals who consume sugar-sweetened beverages might inadvertently increase their energy intake, placing them at a higher risk for weight gain. However, a systematic review (Almiron-Roig, Chen, & Drewnowski, 2003) and more recently published studies (Gadah, Kyle, Smith, Brunstrom, & Rogers, 2015; Martin, Hamill, Davies, Rogers, & Brunstrom, 2015) demonstrate that fluid energy is at least as satiating as solid energy. The inconsistent findings may be partly due to interactions between sensory, cognitive, and physiological factors involved in beverage consumption (Andrade et al., 2008; Cassady, Considine, & Mattes, 2012; Chambers et al., 2013; Glasbrenner et al., 1993; Hogenkamp et al., 2010; Lavin et al., 2002; Yeomans & Chambers, 2011; Zijlstra et al., 2008).

Observational research has demonstrated that eating and drinking episodes are not strongly predicted by hunger and thirst states, respectively (McKiernan, Hollis, McCabe, & Mattes, 2009). One reason for the weak relationships might be because foods and beverages, and therefore eating and drinking, are not always clearly distinguished from one another. Foods and beverages share several defining characteristics (*e.g.,* both items enter the body via the oral-gastric route, they are often flavored and caloric, and can be either liquid, semi-solid, or solid) (Ferrar & Rogers, 2016; Martens & Westerterp-Plantenga, 2012; Martin et al., 2015; Mattes, 2005; McCrickerd, Chambers, & Yeomans, 2014). Therefore, whether an item is perceived as a food or a beverage may depend largely on how it is delivered to the mouth (*i.e.*, bowl with a spoon versus cup with a straw) (Martens & Westerterp-Plantenga, 2012) and by the cognitive beliefs about the item (*i.e.*, foods are filling and beverages are hydrating) (Mattes, 2005; McCrickerd et al., 2014). Because caloric beverages provide flavour, energy, and hydration, they can be thought of as filling, thirst-quenching, or both (Ferrar & Rogers, 2016; Mattes, 2005; McCrickerd et al., 2014). Furthermore, the same beverage can be conceptualized as either filling or thirst-quenching depending on the context (*e.g.,* labelling an item as a filling snack) (McCrickerd et al., 2014) or motivational states (*e.g.,* being hungry may make the consumer more aware of an item's food-like properties) (Ferrar & Rogers, 2016). This ambiguity can pose a problem because if individuals conceptualize consumption of beverages as "drinking", they may not be as cognisant that they are ingesting energy as they would be if they conceptualised their behaviour as "eating" (Ferrar & Rogers, 2016). In an experiment, Cassady and colleagues (2012) manipulated participants' expectations of the postprandial consequences of fluid ingestion. When participants believed they were ingesting a product that would pass through the digestive tract as a liquid (compared to a solid), they felt less satiated and had faster gastric-emptying and oroceal transit times (Cassady et al., 2012). Therefore, conceptualising energy intake as "drinking" might reduce negative physiological feedback on subsequent intake. In addition to consuming more energy in that instance, the increased energy intake is unlikely to be fully compensated for at subsequent ingestive events. Research has demonstrated that increased energy intake from beverages does not reduce energy intake at a concurrent or subsequent meal, resulting in a significant increase in total energy intake (DellaValle, Roe, & Rolls, 2005; Flood, Roe, & Rolls, 2006; Panahi, El Khoury, Luhovyy, Goff, & Anderson, 2013; Rogers, Hogenkamp, et al., 2016).

During a meal, foods and beverages are often consumed together (McKiernan et al., 2009). The combination of food and beverage as part of a meal may occur because the beverage facilitates the process of mastication (Bellisle & Le Magnen, 1981; Kissileff, 1973) and reduces negative consequences of eating, such as thirst (Phillips, Rolls, Ledingham, & Morton, 1984). In addition, as meal satisfaction is determined by the enjoyment of taste experienced during the meal and post-meal fullness (Rogers, Ferriday, Jebb, & Brunstrom, 2016), the addition of a palatable and/or filling beverage to a meal may also occur as a means to increase meal satisfaction. This is particularly relevant when trying to maintain meal satisfaction despite changes to hedonic and satiating aspects of a meal (*e.g.*, reducing the portion size or energy-density of food). For example, focus groups on consumer's attitudes and feelings about portion size reduction revealed that participants, who expected to feel dissatisfied by a reduced portion size, predicted that they would compensate for the "missing food". Specifically, they believed that they would consume a second serving, adding a side dish or beverage, or having a snack later on (Ferrar, Ferriday, et al., in preparation). It is possible that individuals who utilize these compensatory techniques would negate the original efforts to reduce energy intake.

While research has demonstrated that both energy dense foods (*e.g.*, crisps or cake) and beverages (*e.g.*, juice or soda) have relatively weak calorie-for-calorie satiety effects (Brunstrom, Rogers, Pothos, Calitri, & Tapper, 2008; Brunstrom & Rogers, 2009; Martin et al., 2015) and increase long-term energy intake (Malik et al., 2013, 2006; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010; Prentice & Jebb, 2003), the addition of a beverage to a meal might occur at a more implicit level. Anecdotally, the addition of a beverage to a meal is more routine (most meals are consumed with beverages) than the addition of a side dish or snack (only some meals are consumed with accompaniments). When attempting to reduce meal portion size, the addition of an energy dense snack or side dish seems explicitly counterproductive to the original goal of reducing energy intake. In contrast, the addition of a beverage might not be considered counterproductive depending on the perceived properties of the beverage (*i.e.*, hydrating vs. filling). Consequently, an individual actively trying to reduce energy intake may be more likely to use beverages than food to sustain meal satisfaction. Further, the individual may be less aware that the addition of a high-energy beverage could easily undermine their original goal. Therefore, the current study investigated if changes in food portion size, and thus changes in meal satisfaction, influence drinking behaviour based on the flavour and energy properties of the beverages.

Previous research on fluid energy compensation has typically considered the effect of beverage consumption on subsequent food consumption. This often involves using a “preload test-meal” method where, after consuming a fixed portion of a beverage, ad-libitum intake at a subsequent test meal is measured (Rogers, Hogenkamp, et al., 2016). However, outside of the laboratory, beverage choice and intake do not always occur before the selection and consumption of food. Evidence suggests that meals are often pre-planned (Brunstrom, 2014) but the time at which beverage choice occurs during meal planning varies depending on the context. Research suggests that fluid and energy intake often occur concurrently (de Castro, 1988; Engell, 1988; Phillips et al., 1984). However, the co-occurrence of eating and drinking does not clarify when the decisions of what to drink and what to eat are made. Anecdotal evidence suggests that these decisions do not necessarily occur concurrently. For example, when ordering at a fast-food style restaurant, a beverage is often selected after the food has been selected (*e.g.*, “What drink would you like with that?”). In sit-down restaurants, a beverage is typically selected, and often partly consumed, before the food has been selected. Since meal pre-planning is related to subsequent plate-cleaning (Fay et al., 2011), selecting or consuming a beverage before the food has been selected or consumed, may disrupt energy compensation and promote overconsumption. Likewise, approximately 75% of drinking occurs peri-prandially (McKiernan et al., 2009) and the time at which drinking occurs during a meal varies (*i.e.*, beverages may be consumed regularly throughout the meal, towards the end of the meal or even after all of the food has been eaten). To our knowledge, research on fluid energy compensation has not investigated the effect of food consumption on subsequent beverage choice and intake.

The current study focuses on the beverage choice aspect. Despite variability in the timing of the selection and the consumption of foods and beverages within a single meal, individuals are likely to prioritize decisions about the food (as it is the main component of the meal), and subsequently choose a drink as an accompaniment (as it is a secondary component). Therefore, we designed a methodology which assumes that the beverage can be consumed at any point during the meal. However, the key factor is that the food component of the meal is decided on before selecting a beverage due to expected effects of meal pre-planning and subsequent plate-cleaning (Fay et al., 2011) as mentioned above.

An online study was conducted to investigate whether providing individuals with meals smaller or larger than their “ideal” portion sizes would influence their choice of beverage to accompany those meals. It was predicted that an individual presented with a larger than ideal food portion size may feel overwhelmed by the imagined orosensory properties or the degree of expected satiety from the food, and to compensate would choose a less flavourful or lower-energy beverage. Similarly, an individual presented with a smaller than ideal food portion size may feel underwhelmed (*i.e.*, they might predict that consuming the food would not fully satiate them or they would be left wanting additional orosensory reward) and would therefore choose a more flavourful or higher-energy beverage. If changes in beverage choice were in line with the predictions, it would suggest that individuals recognised and considered the varying qualities of different beverages (*i.e.*, water provides hydration, low-energy sweetened (LES) beverages provide hydration and flavour, and high-energy sweetened (HES) beverages provide hydration, flavour and energy), and to a degree, were using them as though they were foods.

METHODS

Participants

Participants (N = 170) were recruited through an online platform, Prolific Academic (Isis Software Incubator Isis Innovation Ltd, 2017). In order to be eligible for the study, participants had to be aged 18 years or older, fluent in English, be a U.K. national, and currently reside in the U.K. Participants could not be vegan, vegetarian, have a history of eating disorders, have any allergies or intolerances to food, or eat or drink while taking part in the study. The eligibility criteria were listed before participants gave informed consent. Additionally, questions checking the eligibility criteria were embedded in a questionnaire at the end of the study to verify eligibility. Data collected from ineligible participants was deleted prior to analysis. Each participant was reimbursed £0.90 for successful completion of the study, which was credited to their Prolific Academic account. Ethical approval was granted by the University of Bristol Faculty of Science Human Research Ethics Committee.

Software

The task was a single-page webapp, built using TypeScript (Version 2.0, Microsoft, 2016) and Angular (Version 2, Google, 2016). Participants could only complete the study from a desktop computer (not a tablet or mobile phone) due to the need for keyboard input to select portion sizes.

The task was tested on the most recent versions of Chrome, Firefox, and Internet Explorer, and CSS (style sheet language) was used to ensure the on-screen size of salient task elements (*e.g.* VAS being 100 mm) was kept constant across devices. The data was stored in a University of Bristol supported database (MySQL) which was hosted on a University of Bristol managed server.

Virtual test foods and beverages

Test foods: Spaghetti Bolognese (Beef), Chicken Chow Mein, and Chicken and Prawn Paella (Sainsbury's ready meals) were selected as the food "preloads". The foods were selected based on characteristics which would increase the likelihood of participants liking and being familiar with at least one of the three foods. Namely, the foods were familiar to British consumers, based on both pilot work and published research (Jaworowska, Blackham, Stevenson, & Davies, 2012; Wrieden, Gregor, & Barton, 2008), represented three different cuisines, and a variety of main-ingredients were included (*i.e.*, beef, chicken and prawns). Nutritional information for the three foods is listed in Table 1. Each food was photographed, with the use of a high-resolution digital camera, on the same white plate (255 mm diameter). Particular care was taken to maintain constant lighting conditions and plate position in each photograph. Photograph sets consisted of 50 photos, ranging from 20 kcal to 1000 kcal in equicaloric steps (preserving the same overall macronutrient composition within each set of images). The name of the food was included in the top left-hand corner of every image (Brunstrom et al., 2016; Hinton et al., 2013; Wilkinson et al., 2012). Figure 6 (in supplementary material) displays images of the five portion sizes (and shows the weight in grams) for each of the foods.

Test beverages: Low and high energy versions of a blackcurrant non-carbonated soft-drink were selected as the sweetened beverages as these drinks are commercially available in the United Kingdom (Sadowska et al., 2017). Non-carbonated beverages were selected to avoid possible effects of carbonation on appetite (Moorhead, Livingstone, Dunne, & Welch, 2008). The brand Ribena and Ribena light (Lucozade Ribena Suntory Ltd.) was selected as it is well-known by British consumers (Ng, Ni Mhurchu, Jebb, & Popkin, 2012). Highland Spring Still Water (Highland Spring Ltd.) was selected as the brand of water, as it is commercially available in stores where Ribena and Ribena light are sold and the bottle has a similar shape to Ribena and Ribena light bottles. Nutritional information for the three beverages is listed in Table 1. Each beverage was photographed with the use of a high-resolution digital camera. The photographs were of each beverage in its 500 ml bottle. The front of the label, with the name of the beverage and any advertised information, was visible.

Table 1 Nutritional information for test beverages and foods (values per 100 ml for beverages and per 100 g for foods).

	Energy (kJ)	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrates (g)	Salt (g)
Beverages						
Water	0	0	0	0	0	<0.01
LES beverage (Ribena light)	20	5	0	0	0.6	<0.01
HES beverage (Ribena)	175	41	0	0	10.0	<0.01
Foods						
Spaghetti Bolognese	593	141	7.2	5.3	16.2	0.28
Chicken and Prawn Paella	553	132	7.7	4.2	14.8	0.60
Chicken Chow Mein	343	81	6.6	2.1	8.9	0.72

Measures

Beverage choice task: Participants completed fifteen trials presented in a random order. Each trial displayed one of the three test foods (Spaghetti Bolognese, Chicken Chow Mein, and Chicken and Prawn Paella) in one of five portion sizes (100 kcal, 300 kcal, 500 kcal, 700 kcal, and 900 kcal). Participants were instructed to select one of the three beverage options (water, Ribena light, or Ribena) to accompany the meal. Participants were informed that they should imagine consuming half of the bottle (250 ml). This volume of fluid was selected as it is the recommended serving. Specifically, participants were presented with the following instructions:

“Imagine that you are having the following meal for lunch. Imagine that you must eat everything on the plate and that no other foods will be available until dinnertime! Please click on the beverage that you would have with this meal, knowing that you must consume 250 ml of the beverage.”

Ideal portion size task: Participants completed four trials presented in a random order. In each trial, one of the fifty portion sizes (20-1000 kcal) was randomly selected as the starting portion size. The photographs were loaded with sufficient speed that continuous key depression gave the appearance that the change in portion size was animated. Depressing the left or right keyboard arrow key caused the portion size to decrease or increase, respectively (Brunstrom et al., 2016; Hinton et al., 2013; Wilkinson et al., 2012). The first trial allowed participants to practice the task by changing the portion size of a plate of peanuts (a food that would not appear elsewhere during the experiment). The following three trials, which were presented in a random order, consisted of selecting ideal portion sizes for the three test foods (Spaghetti Bolognese, Chicken Chow Mein, and Chicken and Prawn Paella). Specifically, participants were instructed to “Imagine that you have just sat down to have the following meal for lunch. No other foods are available during lunch and you will not be able to eat anything else until dinnertime,” and to “Select the amount that you would eat” (Brunstrom et al., 2016).

Beverage and Food ratings: Participants were asked to rate each of the three foods (500 kcal portions) and each of the three beverages (250 ml portions) on various characteristics, regardless of whether they had ever consumed them. If they had never consumed the beverage or food, they were instructed to make the ratings based on a very similar beverage or food that they had consumed before. To assess familiarity, participants reported how frequently they consumed each beverage and food on a 9-point scale (ranging from several times a day to never). They also reported how many calories they thought the food and beverages contained. The following ratings were rated on 100 mm VAS (anchored from “Not at all” to “Extremely”).

Participants reported how much they liked the food and beverages. For each food, they reported how filling and thirst-causing they perceived it to be. For each beverage, they reported how much they enjoyed its taste, and how filling, energising, nutritious, hydrating, and thirst-quenching they perceived it to be.

Appetite ratings: Participants reported levels of hunger, thirst and fullness using 100 mm VAS (anchored from “Not at all” to “Extremely”).

Habitual behaviour: Participants reported which beverages they usually consumed from the following choices: a) mostly diet (“zero-calorie / sugar-free”), b) mostly regular (“sugar-containing”), c) a mix of both, or d) neither.

Demographics: Participants reported their age (years), gender, ethnicity, and highest level of education.

Weight status and dietary information: Participants reported their height and weight (metric or imperial units), whether they considered themselves to be overweight, and if they were currently dieting. If participants were not currently dieting, they were asked if they had dieted in the past. If participants had dieted in the past, they were asked to record the number of times they had dieted in the past 12 months. Participants also completed the cognitive restraint subscale of the Three Factor Eating Questionnaire R21 (Tholin, Rasmussen, Tynelius, & Karlsson, 2005), which measures conscious restriction of energy intake (Stunkard & Messick, 1985).

Demand awareness: Participants were asked to describe what they thought the study was investigating.

Procedure

The study took approximately 10 minutes to complete. Participants were instructed to read information about the study and the inclusion/exclusion criteria. After providing informed consent, they completed appetite ratings, the “Ideal food portion size” task (including the practice trial), and the “Beverage choice” task. Participants then rated the study foods and beverages, and filled out the questionnaire on demographics and dietary behaviour. Before debriefing participants, demand awareness was measured. As the study was hosted online, an “attention check” question was included to ensure that valid data was collected (Oppenheimer, Meyvis, & Davidenko, 2009). Embedded among the appetite ratings, a VAS for “tiredness” with unique instructions to refrain from making a rating on the scale, but to instead click on the word “tired” was included. In addition, at the end of the study, exclusion criteria questions (history of eating disorders, vegetarian or vegan, food allergies or intolerances, last eating episode, and last drinking episode) were included to ensure the dataset did not include participants who violated the exclusion criteria.

Data Analysis

Data selection: It was predetermined that analyses would focus on the food that was most liked and most familiar to participants, and that follow-up analyses would be performed on the other two foods to ensure that any effects could be replicated with other types of foods (even ones that were less liked). It was expected that participants who disliked or were unfamiliar with any of the beverage options presented in this study might continually select the same beverage despite changes in food portion size. These potential confounders, *i.e.*, liking for and familiarity with the three beverages, might influence beverage choice, inaccurately depicting participants’ sensitivity to changes in flavour and energy provided by the meals. Therefore, it was decided that these variables would be controlled for in the statistical models. If liking and familiarity ratings of the beverages are correlated, only liking will be included. Beverage liking will be prioritized over beverage familiarity as beverage liking is a 100 mm interval measurement (as opposed to the 9-point ordinal measurement used to assess beverage familiarity) and therefore will provide more varied and meaningful data on drinking behaviour.

Analysis strategy: The data were analysed using SPSS Statistics (IBM Corp, 2015) and STATA (StataCorp, 2015). As the three beverages selected for this study could be defined as ordered categorical outcome variables: HES beverage = (+) energy (+) flavour; LES beverage = (-) energy (+) flavour, and water = (-) energy (-) flavour, ordinal logistic regression was used for all analyses investigating relationships between this variable and its predictors (*i.e.*, food portion size, ideal food portion size, and liking for the beverages). It should be noted here that due to the repeated measures nature of the study (*i.e.*, there are multiple observations for each participant), the assumption of independency of observations is violated and a conventional ordinal logistic regression analysis is therefore inappropriate. To address this, all models were specified as multilevel ordinal logistic regression models, where observations (level 1) were nested within participants (level 2), as described in Field and Wright (2011) and Hayes (2006). The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were used for model selection, predicted probabilities and confidence intervals were used for model prediction, and likelihood ratio tests were used for significance testing.

The hypothesized model (Model 1) was produced using a multilevel ordinal regression analysis to predict beverage choice using grand mean centered (i.e., zero represents the average portion size) food portion size, grand mean centered ideal food portion size, and the interaction between the two as the predictors. Grand mean centered beverage liking was included as a covariate. If Model 1 predicted beverage choice, exploratory models (identical to Model 1 with the exception that each model would include an additional covariate) would be carried out to assess the strength and basis of the relationship between food portion size and accompanying beverage choice.

RESULTS

Participants

Four participants were removed from the analyses because they had never consumed any of the three foods. The remaining sample consisted of 166 participants, 103 women and 63 men, of White, Black, Asian, mixed, and other descent, aged 18 to 81 (M = 34.2 ± 12.8) years. Fifty percent of the sample held an undergraduate degree and 18% held a postgraduate degree. BMI ranged from 15 to 45 (M = 25.5 ± 5.3) kg/m^2 and dietary restraint scores ranged from 9 to 21 (M = 14.5 ± 2.3). Twenty-nine percent of the sample was currently dieting. Participants rated their hunger (M = 38.0 ± 26.0), thirst (M = 50.0 ± 24.0), and fullness (M = 51.0 ± 25.0). Three participants correctly guessed the study aims, but were retained in the analyses as removing their data did not affect the results.

Beverage characteristics

Thirty-four percent of the sample normally consumed diet beverages, 35% normally consumed regular beverages, 17% normally consumed a mix of both diet and regular beverages, and 14% normally consumed neither. Forty-eight percent of the sample had never tasted the LES beverage and 20% of the sample had never tasted the HES beverage. Table 2 lists participants' caloric estimations for a 250 ml serving of the beverages. A Friedman test revealed that familiarity with the test beverages differed (p <.001). A Wilcoxon signed ranks test specified that water was consumed more frequently than both the LES (Z = - 10.81, p < .001) and HES beverage (Z = - 10.66, p < .001). Repeated measures analysis of variance (ANOVA) tests were conducted to determine how the three beverages may have differed in their perceived properties. The following results have had Greenhouse-Geisser corrections applied. Participants rated liking and enjoyment of taste highest for water, followed by the HES beverage, and then the LES beverage ($p < .001$). Water was perceived as more hydrating ($p < .001$), thirst-quenching ($p < .001$), and nutritious ($p < .001$) than both the sweetened beverages. The HES beverage was perceived as more filling ($p < .001$) and more energizing ($p < .001$) than both the low-energy beverages ($p < .001$).

Data selection

Ideal food portion size (kcal) for all three foods was as follows: Spaghetti Bolognese ($M = 468.0 \pm 191.0$), Chicken and Prawn Paella ($M = 449.0 \pm 209.0$), and Chicken Chow Mein ($M = 357.0 \pm 210.0$). Table 2 lists participants' caloric estimations for a 500 kcal serving of each food. The three foods were rated as equally filling ($p = .220$). Chicken Chow Mein and Chicken and Prawn Paella were believed to increase thirst to a greater degree than Spaghetti Bolognese ($p < .001$). Participants liked Spaghetti Bolognese the most, followed by Chicken Chow Mein, and then Chicken and Prawn Paella ($p < .001$). A Friedman test revealed that there was a significance difference in familiarity with the three foods, $p < .001$. A Wilcoxon Signed Ranks tests revealed that participants were more familiar with Spaghetti Bolognese than Chicken Chow Mein ($p < .001$) and Chicken and Prawn Paella ($p < .001$). As Spaghetti Bolognese was most liked and most familiar to participants, it was selected for the main data analysis.

Table 2 Participant energy content estimations of study foods and beverages

	Estimated energy M (SD)	Actual energy
Spaghetti Bolognese (354.6 g)	883.8 (502.0) kcal	500 kcal
Chicken and Prawn Paella (378.8 g)	880.8 (457.4) kcal	500 kcal
Chicken Chow Mein (617.3 g)	918.8 (490.9) kcal	500 kcal
Water (250 ml)	16.2 (88.7) kcal	0 kcal
LES beverage (250 ml)	207.9 (419.3) kcal	10 kcal
HES beverage (250 ml)	455.4 (482.3) kcal	103 kcal

Effects of portion size on beverage choice

As predicted, liking and familiarity ratings for each beverage were correlated (water: r = .52, $p < .001$; LES beverage: r = .63, $p < .001$; HES beverage: r = .69, $p < .001$). In addition to the justifications stated in the methods section, the results also supported prioritizing beverage liking over beverage familiarity. That is, a similar proportion of participants were as unfamiliar with Ribena light (48%) as they were with diet beverages in general (49%) suggesting that participant unfamiliarity with the specific LES beverage used in this study was due to a dislike of diet beverages generally (perhaps due to skepticism regarding low-energy sweeteners (Carocho, Morales, & Ferreira, 2017). Liking ratings among the three beverages were also correlated (water and LES beverage, r = -.26, $p = .001$; water and HES beverage, r = -.23, $p = .003$; LES beverage and HES beverage, r = .58, $p < .001$). Therefore, liking for a single beverage was entered as the covariate to represent beverage liking in the model. Water was not selected to represent beverage liking as it was the most neutral option; the HES was selected over the LES as it possessed all three beverage properties (hydration, flavor, and energy).

The AIC and BIC of Model 1 (AIC = 1000.0, BIC = 1033.1) was compared to those of the constant only model (AIC = 1220.2, BIC = 1234.3) indicating that the predictors as a set reliably distinguished between the three beverage choices. Full results for Model 1 are reported in Table 3. Food portion size was a significant predictor of beverage choice ($p < .001$). The likelihood of choosing water increased as portion size of the food increased, the likelihood of choosing the HES and LES beverages decreased as portion size of the food increased (results presented in Figure 1). However, food portion size and ideal food portion size did not interact to predict beverage choice. Additionally, beverage choice was affected by how much the HES beverage was liked ($p < .001$).

Table 3 Multilevel Ordinal Regression Results (Spaghetti Bolognese).

	Model 1				Model 2				Model 3				Model 4			
	Coefficient		95% C.I.		Coefficient		95% C.I.		Coefficient		95% C.I.		Coefficient		95% C.I.	
Cut-off water[a]	-3.47	***	-4.10	-2.85	-3.70	***	-4.44	-2.97	-3.47	***	-4.08	-2.86	-3.44	***	-4.04	-2.83
Cut-off LES beverage[a]	-1.95	***	-2.48	-1.42	-2.18	***	-2.83	-1.53	-1.94	***	-2.45	-1.42	-1.91	***	-2.42	-1.40
Food portion size	0.11	***	0.09	0.13	0.11	***	0.09	0.13	0.11	***	0.09	0.13	0.11	***	0.09	0.13
Ideal food portion size	-0.02		-0.06	0.03	-0.01		-0.06	0.04	-0.01		-0.05	0.04	-0.04		-0.09	0.01
Food portion size*Ideal food portion size	-0.01		-0.01	0.01	0.01		-0.01	0.01	0.01		-0.01	0.01	-0.01		-0.01	0.01
Liking for HES beverage	-0.52	***	-0.68	-0.36	-0.52	***	-0.67	-0.36	-0.51	***	-0.67	-0.36	-0.51	***	-0.66	-0.35
Gender					-0.63		-1.55	0.29								
Restraint									0.25	*	0.05	0.45				
Food portion size*Restraint									0.01	*	0.01	0.02				
Liking for the food													0.45	**	0.17	0.62
Participant Variance	6.15				6.02				5.62				5.39			

*** $p < .001$, ** $p < .01$, * $p < .05$
[a] Reference category: HES beverage

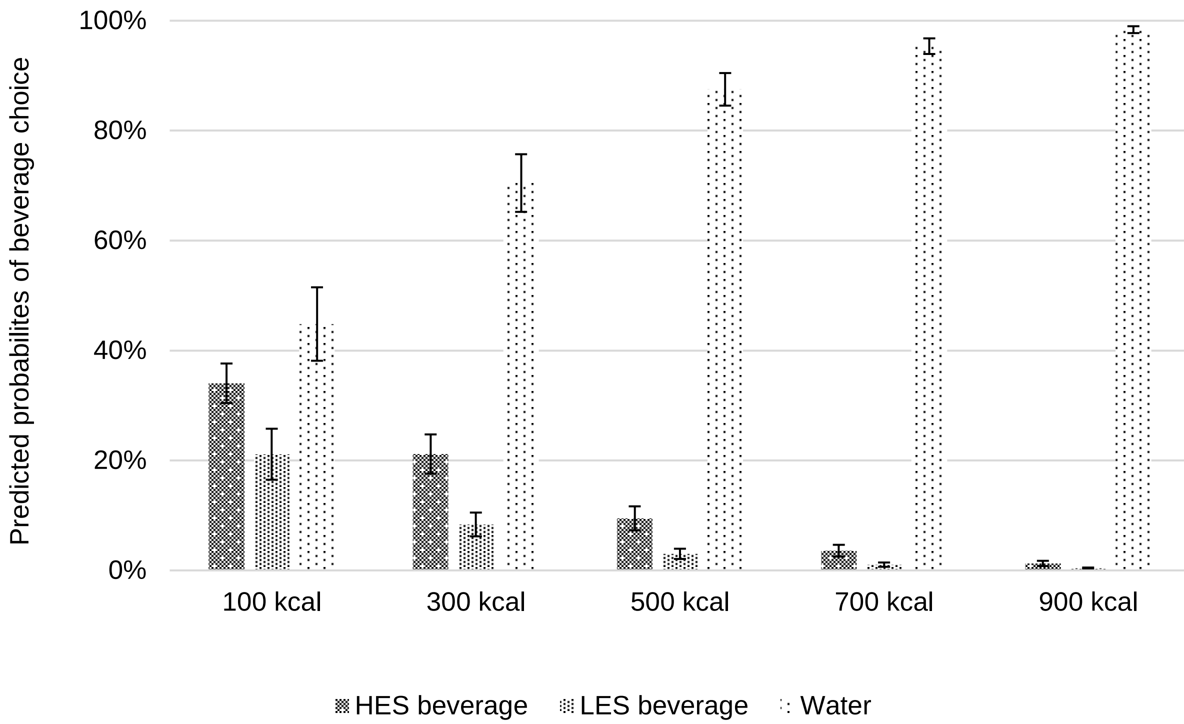

Figure 1 Predicted probabilities of Model 1 for beverage selection when presented with a 100kcal, 300kcal, 500kcal, 700kcal, and 900kcal of Spaghetti Bolognese. Error bars indicate 95% confidence intervals.

Exploratory analyses

Exploratory analyses were conducted to assess the effects of gender, dietary behavior, and food liking on the relationship between food portion size and accompanying beverage choice. Gender was selected as a covariate due to gender differences in energy intake (Brunstrom et al., 2008; Owen et al., 1986, 1987) and energy compensation for liquid and semi-solid preloads (Davy, Van Walleghen, & Orr, 2007; Gadah et al., 2015; Ranawana & Henry, 2010). Dietary behavior was included as a covariate because dieting may lead to “healthier” or more restrictive choices (*e.g.*, err towards selecting low-energy beverages). However, if a dieter is presented with portions larger than their ideal they may demonstrate counter-regulatory eating (Herman & Polivy, 1983). That is, since the meal has already pushed them past a cognitive “diet boundary” they may choose the caloric beverage (“what the hell effect”). Food liking was included as a covariate since it predicts food reward and portion size (Brunstrom & Shakeshaft, 2009). Therefore, the extent to which a participant likes the food might influence their ideal food portion size and in turn their beverage choice.

Gender: Male and female participants did not differ in their ideal food portion size selections $t(164) = 1.74$, $p = .08$. Model 2 was identical to Model 1 other than the addition of gender as a second covariate. The full results are reported in Table 3. The AIC and BIC of Model 2 (AIC = 1000.3, BIC = 1038.0) was compared to those of the constant only model (AIC = 1220.2, BIC = 1234.3) and Model 1 (AIC = 1000.0, BIC = 1033.1) indicating that the predictors as a set reliably distinguished between the three beverage choices, but that the addition of gender as a covariate was not an improvement over Model 1. Additionally, gender did not have a significant effect on beverage choice.

Dietary behaviour: In this study, dietary behaviour was assessed by three variables: body mass index, diet status (currently dieting: yes or no), and dietary restraint scores. Body mass index was not used as a covariate because the measure does not differentiate very well between body fat, muscle mass, and bone density (Shah, Braverman, Cerhan, Flint, & Hannan, 2012). In addition, missing data for this variable would have reduced the sample size and power for the analyses. Dietary restraint (a continuous variable) was selected over diet status (a categorial variable) as the variables were related ($r = .33$, $p < .001$) and a continuous variable offered a greater range of information on dietary behavior. Participants’ level of dietary restraint was correlated with their ideal portion sizes ($r = -.17$, $p < .001$). Model 3 was identical to Model 1 other than the addition of grand mean centered dietary restraint as a second covariate. The full results are reported in Table 3. The AIC and BIC of Model 3 (AIC = 998.1, BIC = 1035.8) was compared to those of the constant only model (AIC = 1220.2, BIC = 1234.3) and Model 1 (AIC = 1000.0, BIC = 1033.1) indicating that the predictors as a set reliably distinguished between the three beverage choices, and that the addition of dietary restraint as a covariate was an improvement over Model 1. Additionally, dietary restraint had a significant effect on beverage choice, in that the participants highest in dietary restraint were least likely to select the sweetened beverages (p = .01) (Figure 2). Dietary restraint also interacted with food portion size when predicting beverage choice (p = .01). The effect of food portion size on beverage choice was plotted in three separate groups based on their level of dietary restraint (high = upper quartile; medium = middle; low = lower quartile). Participants highest in dietary restraint were more likely to select HES beverage with the 100 kcal portion of food than the two other groups (Figure 3).

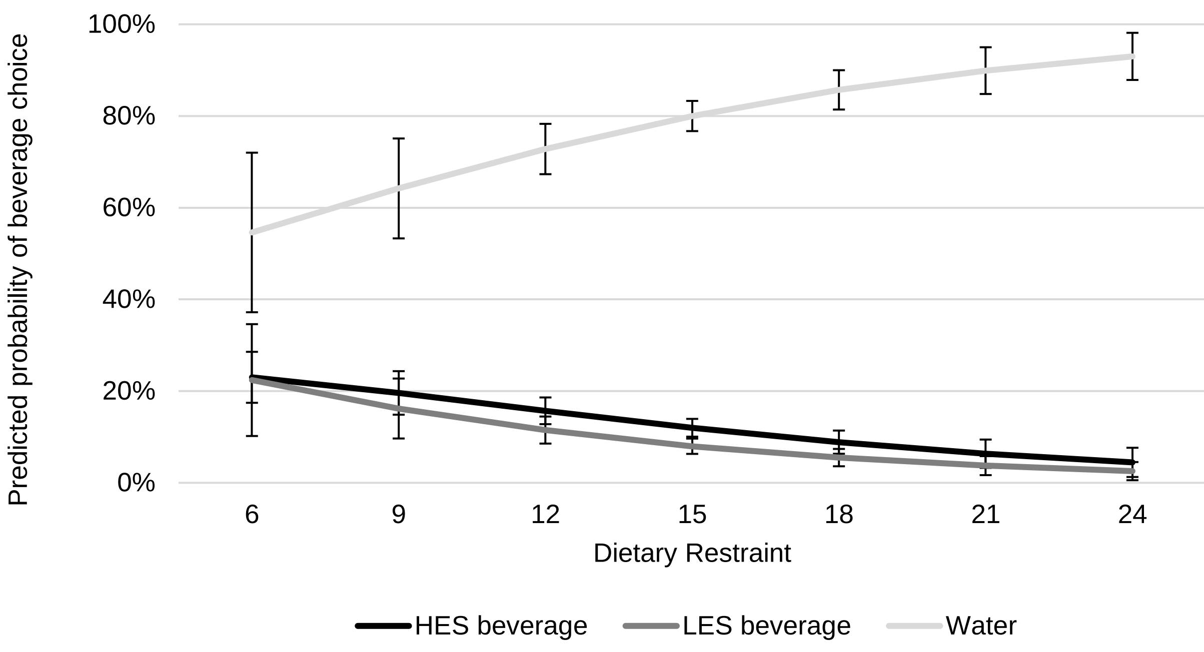

Figure 2 Predicted probabilities of Model 3 for beverage selection based on participant dietary restraint. Error bars indicate 95% confidence intervals.

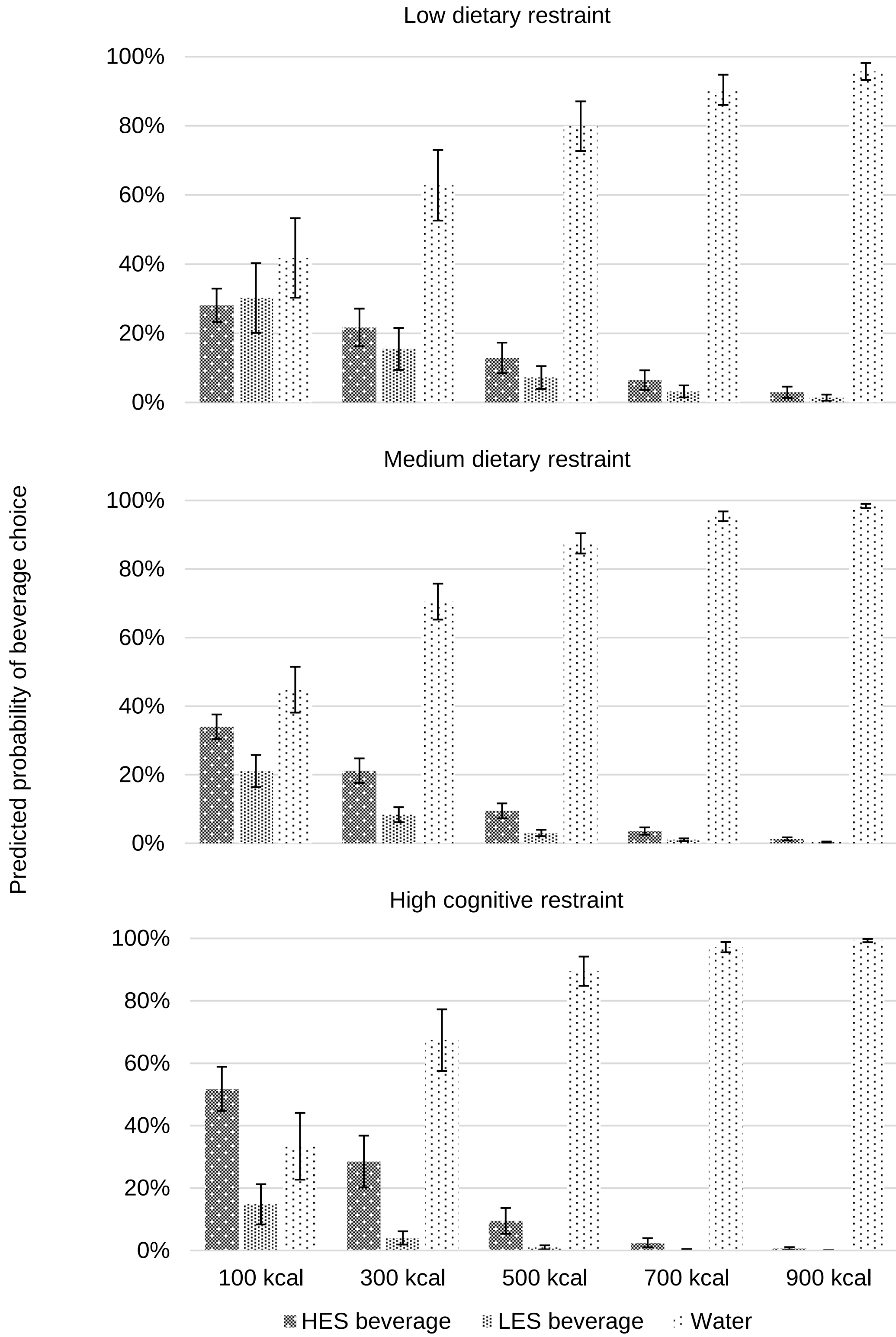

Figure 3 Predicted probabilities of Model 3 for beverage selection in participants with low, medium, and high cognitive restraint. Error bars indicate 95% confidence intervals.

Liking for the food: Participants' liking for the food was correlated with their ideal portion sizes (r = -29, $p < .001$). Model 4 was identical to Model 1 other than the addition of grand mean centered liking for the food as a second covariate. The full results are reported in Table 3. The AIC and BIC of Model 4 (AIC = 990.8, BIC = 1028.5) was compared to those of the constant only model (AIC = 1220.2, BIC = 1234.3) and Model 1 (AIC = 1000.0, BIC = 1033.1) indicating that the predictors as a set reliably distinguished between the three beverage choices, and that the addition of liking for the food as a covariate was an improvement over Model 1. Additionally, liking for the food had a significant effect on beverage choice ($p = .001$). A test of the model 4 against a constant only model was statistically significant (chi square = 239.4, $p < .001$, df = 5). The selection of water increased and the likelihood of choosing the sweetened beverages decreased as liking for the food increased (Figure 4).

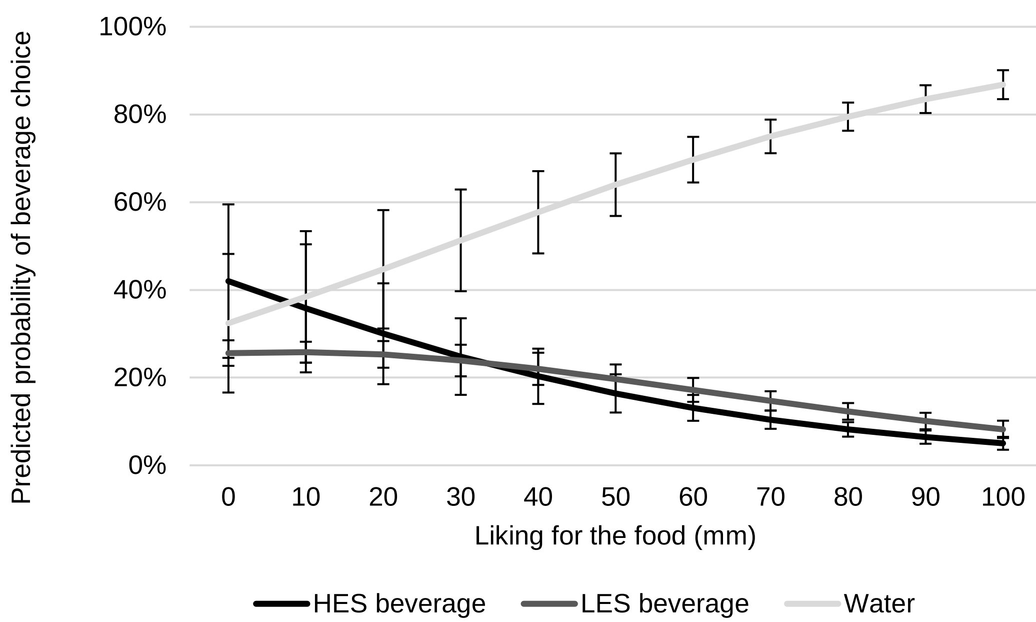

Figure 4 Predicted probabilities of Model 4 for beverage selection based on how much the food (Spaghetti Bolognese) was liked. Error bars indicate 95% confidence intervals.

Replication of effects in additional test foods

For Chicken and Prawn Paella, the AIC and BIC of Models 1 (AIC = 881.6, BIC = 914.6), 2 (AIC = 883.1, BIC = 920.8), 3 (AIC = 883.0, BIC = 925.5) and 4 (AIC = 869.7, BIC = 912.2) were compared to those of the constant only model (AIC = 1014.4, BIC = 1028.5), indicating that the predictors as a set reliably distinguished between the three beverage choices, and that the fourth model (which included liking for the food as a covariate) was the best fit for the data (Table 4 displays the full results). Food portion size ($p < .001$), liking for HES beverage ($p < .001$) and liking for the food ($p = .001$) had significant effects on beverage choice. Predicted probabilities of choosing the HES beverage, the LES beverage, and water were plotted against food portion size and liking for the food separately (data not shown). The data resembled the data using Spaghetti Bolognese. Specifically, the likelihood of choosing water increased as portion size of the food increased, and the likelihood of choosing the HES and LES beverages decreased as portion size of the food increased. The likelihood of choosing water increased and the likelihood of choosing HES and LES beverages decreased as liking for the food increased. In addition, there was a significant interaction between liking for the food and food portion size ($p = .01$). The effect of portion size on beverage choice in participants who had low (lower quartile), medium (middle), and high (upper quartile) liking for the food was plotted separately. Selecting the HES beverages with the smaller food portion sizes occurred to a larger degree in participants who liked the food less (Figure 5). Unlike Spaghetti Bolognese, controlling for dietary restraint did not better predict the effect of the portion size of Chicken and Prawn Paella on beverage choice.

Table 4 Multilevel Ordinal Regression Results (Chicken and Prawn Paella).

	Model 1				Model 4			
	Coefficient		95% C.I.		Coefficient		95% C.I.	
Cut-off water[a]	-4.16	***	-4.91	-3.40	-4.24	***	-5.00	-3.49
Cut-off LES beverage[a]	-2.67	***	-3.32	-2.03	-2.75	***	-3.40	-2.10
Food portion size	0.08	***	0.07	0.10	0.09	***	0.07	0.11
Ideal food portion size	-0.01		-0.06	0.04	-0.04		-0.09	0.01
Food portion size*Ideal food portion size	-0.01		-0.01	0.01	-0.01		-0.01	0.01
Liking for HES beverage	-0.55	***	-0.73	-0.37	-0.53	***	-0.71	-0.36
Liking for the food					0.33	**	0.14	0.52
Food portion size*Liking for the food					0.01	*	0.01	0.01
Participant Variance	7.68				7.09			

*** $p < .001$, ** $p < .01$, * $p < .05$
[a] Reference category: HES beverage

Table 5 Multilevel Ordinal Regression Results (Chicken Chow Mein).

	Model 1				Model 4			
	Coefficient		95% C.I.		Coefficient		95% C.I.	
Cut-off water[a]	-3.70	***	-4.39	-3.01	-3.70	***	-4.38	-3.01
Cut-off LES beverage[a]	-2.10	***	-2.69	-1.51	-2.10	***	-2.69	-1.51
Food portion size	0.10	***	0.08	0.12	0.10	***	0.08	0.12
Ideal food portion size	-0.04		-0.08	0.01	-0.04		-0.09	0.01
Food portion size*Ideal food portion size	-0.01		-0.01	0.01	-0.01		-0.01	0.01
Liking for HES beverage	-0.56	***	-0.74	-0.39	-0.56	***	-0.74	-0.39
Liking for the food					0.06		-0.10	0.21
Participant Variance	7.63				7.63			

*** $p < .001$, ** $p < .01$, * $p < .05$
[a] Reference category: HES beverage

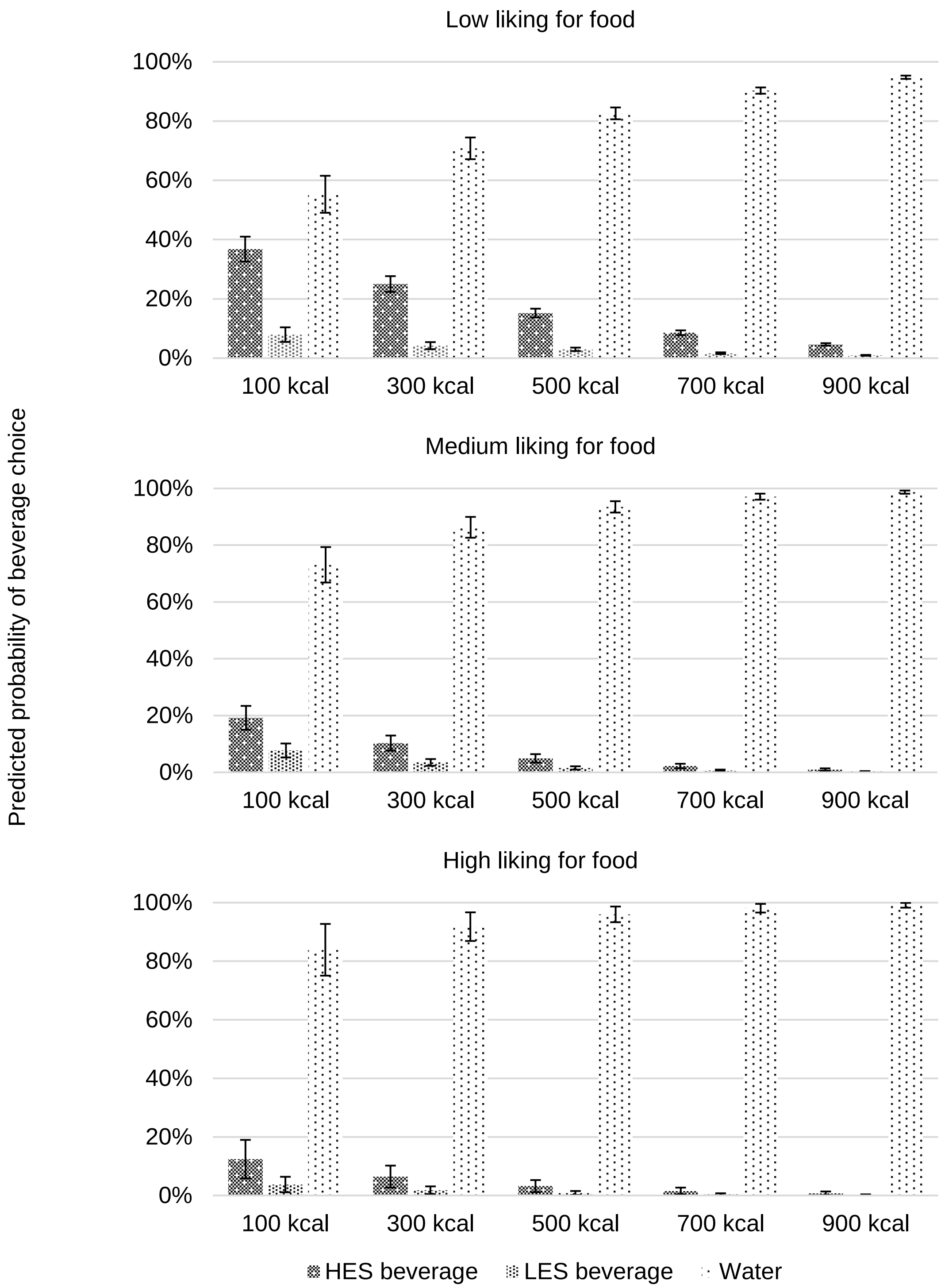

Figure 5 Predicted probability of beverage selection when presented with 100kcal, 300kcal, 500kcal, 700kcal, and 900kcal portions of the food (Chicken and Prawn Paella) in participants who had low, medium, and high liking for the food (Chicken and Prawn Paella). Error bars indicate 95% confidence intervals.

For Chicken Chow Mein, the AIC and BIC of Models 1 (AIC = 986.4, BIC = 1019.4), 2 (AIC = 987.4, BIC = 1025.1), 3 (AIC = 986.2, BIC = 1028.7), and 4 (AIC = 988.3, BIC = 1026.1) were compared to those of the constant only model (AIC = 1182.3, BIC = 1196.5), indicating that the predictors as a set reliably distinguished between the three beverage choices and that the models which included covariates were not improvements over Model 1. Table 5 displays the full results. While liking for the food and dietary restraint did not directly or indirectly influence beverage choice (as seen in the other foods), the main effects of food portion size (p <. 001) and liking for the HES beverage ($p < .001$) on beverage choice persisted. Predicted probabilities of choosing the HES beverage, the LES beverage, and water were plotted against food portion size and liking for the food separately (data not shown). The data resembled the data using Spaghetti Bolognese and Chicken and Prawn Paella. Specifically, the likelihood of choosing water increased as portion size of the food increased, and the likelihood of choosing the HES and LES beverages decreased as portion size of the food increased.

DISCUSSION

This study assessed the influence of food portion size on subsequent beverage choice. The rationale behind the study was that two components of the meal, food and drink, modulate meal satisfaction (a combination of enjoyment of taste and post-meal fullness) (Rogers, Ferriday, et al., 2016). Therefore, reducing food portion size would reduce meal satisfaction, and participants would be more likely to add a flavoured beverage to the meal to sustain satisfaction (Ferrar, Ferriday, et al., in preparation). The results confirm this hypothesis: participants were more likely to choose the sweetened beverages as the food portion size decreased in size. This pattern of results was first observed in the most familiar and well-liked test food and then replicated in the two remaining test foods. To our knowledge, this is the first demonstration that food portion size can influence subsequent beverage choice.

It should be noted that the LES beverage was an unpopular choice amongst participants (perhaps due to skepticism regarding low-energy sweeteners (Carocho et al., 2017), but the models accounted for individual differences in beverage preferences. A limitation of the study design is that liking for the HES beverage was included in the models, and liking for HES beverages is not necessarily indicative of LES beverage avoidance. However, repeating the analyses using liking for the LES beverage instead did not change the conclusions (data not shown). Nonetheless, the study design can be improved upon in the future by the inclusion of more comprehensive measurements of beverage preference (*e.g.*, ranking beverages) or more direct measurements of LES beverage avoidance in the models (*e.g.*, “Do you often purchase "diet" products?” or “Do you try to avoid artificial sweeteners?”).

In the present study, when food portion size was smaller or larger than ideal, it was predicted that recognising the food-like properties of beverages (*e.g.,* energy, flavor) would increase the likelihood of those beverages being selected to accompany the meal. That is, participants would select beverages with food-like properties to accompany the meal as a means to maintain an ideal level of energy and flavour provided by the meal (*i.e.*, their satisfaction with the meal). Participants tended to choose water with large food portion sizes suggesting that they maintained meal satisfaction by attempting to avoid a) feeling too full and/or b) consuming too many calories. Participants tended to choose the sweetened beverages with small food portion sizes. Those who chose the HES option may have maintained meal satisfaction by attempting to a) prolong the enjoyment of taste and b) ensure that they would reach fullness. Whereas, participants who chose the LES option might have been maintaining meal satisfaction through taste alone. Indeed, this is one of the reasons why consumption of LES beverages might help individuals to reduce energy intake and lose weight (Rogers, Hogenkamp, et al., 2016).

The pattern of beverage choices with varying portions of food can be interpreted as compensation for anticipated changes in eating enjoyment, satiation, and energy intake.

Overall, the results suggest that participants recognised the food-like properties (*e.g.*, energy and flavour) of the caloric beverage which is in line with the Martin and colleagues' finding that snacks paired with caloric beverages were rated as being more filling than the same snacks paired with low caloric beverages or water (Martin et al., 2015). In the present study, the HES beverage was perceived as the most energising, filling, and caloric beverage. Therefore, it is possible that the HES beverage was less likely to be selected with larger food portion sizes because participants were avoiding a beverage which would further enhance the energy content of the meal, satiation or both. In theory, a beverage's ability to enhance meal enjoyment depends on how enjoyable the beverage tastes. Comparing the frequency with which the LES beverage (which tastes sweet but contains little energy) and the HES beverage (which tastes sweet and provides significant energy) were chosen can give some indication about whether participants prioritized the enjoyment of taste or post-meal fullness when putting together their meals. There was little difference in the likelihood of the HES and LES beverages being selected when the food portion size was 500 kcal or more. Below 500 kcal, as food portion size decreased, participants were more likely to choose the HES beverage over the LES beverage, suggesting that beverage selection was motivated by expected satiation and conscious control of energy intake.

An alternative explanation to the pattern of beverage choice is that changes in food portion size did not provoke concerns over hunger, but over thirst. Participants might have expected that a greater amount of food would require a thirst-quenching beverage to alleviate thirst caused by the food. Water was perceived as the most thirst-quenching, which may have increased the likelihood of it being selected over the sweetened beverages with larger food portion sizes. To assess the likelihood of this explanation, additional analyses were conducted which revealed that (a) how thirsty participants expected to be after consuming the food, and (b) the perceived thirst-quenching and hydrating properties of the beverages, did not predict beverage choice nor interact with food portion size to predict beverage choice. Therefore, the former explanation is more probable.

It was also predicted that an individual's ideal food portion size would determine which food portion sizes were perceived as too small or too large for each participant, and therefore would interact with food portion size to predict beverage choice. It is unclear why his relationship was not found. Part of the rationale for investigating the influence of ideal food portion size was to identify a threshold below ideal food portion size, just before the reduction is detectable (McCaig, Ferriday, Benton, Brunstrom, & Rogers, 2016) (*i.e.,* the point at which behavioural compensation would occur (Rogers, Ferriday, et al., 2016)). This might, in turn, identify the optimal range for successful energy restriction and ultimately weight loss. Future research should continue to attempt to identify this threshold.

Liking for Spaghetti Bolognese and Chicken and Prawn Paella predicted beverage choice. That is, the less the food was liked the more likely participants were to select the HES beverage. Although this was not hypothesized, liking for the food independently affecting beverage choice aligns with the proposal of meal satisfaction. Liking for a food influences the reward associated with eating that food (eating enjoyment) (Rogers & Hardman, 2015), which in turn strongly predicts expected meal satisfaction (Rogers, Ferriday, et al., 2016; Shahrokni, Ferriday, Motou, Brunstrom, & Rogers, 2018). If liking for the food (and consequently expected meal satisfaction) are low, pleasant additions to the meal (*i.e.*, energy and flavour) that would increase overall satisfaction might be sought out.

From the present data, it is unclear why liking for Chicken Chow Mein did not also predict beverage choice. Liking for Chicken Chow Mein was intermediate between the other two foods. One possibility is that this effect of liking is relevant only in foods that are more strongly liked or disliked. Another possibility is that the effect of liking was less relevant because there was a strong visual cue of fillingness (the portions of Chicken Chow Mein were larger, in terms of weight, relative to the other two foods). The latter explanation is consistent with the finding that meal satisfaction is determined by fullness, as well as food liking (Rogers, Ferriday, et al., 2016). Further, expected meal satisfaction is predicted not only by expected eating enjoyment, but by expected fullness, albeit to a lesser degree (Shahrokni et al., 2018).

For Chicken and Prawn Paella, there was also an interaction between liking for the food and food portion size on beverage choice. That is, participants who liked the food less were more likely to select the sweetened beverages with large food portion sizes than participants who liked the food more. This interaction effect may have been unique to Chicken and Prawn Paella as it was the least liked food. The group who liked this food less may have strongly disliked this food. Therefore, they may have been more motivated to seek out compensatory reward from the beverages (whether to increase enjoyment of taste or mask the taste of the food), even if energy intake or fullness would be increased as a result.

For Spaghetti Bolognese, participants higher in dietary restraint were more likely to choose water and less likely to choose the sweetened beverages compared to participants lower in dietary restraint. However, when the food portion size was small, participants high in dietary restraint were more likely to choose the HES beverage and less likely to choose the low-energy options than participants low in dietary restraint. From the present data, it is unclear why the effects of dietary restraint differed across foods and this warrants further investigation. Perhaps, differences in how much the three foods were liked by participants might explain the differing results. For example, Spaghetti Bolognese was the most liked food. Exposing restrained eaters to palatable food stimuli primes goals about eating enjoyment, resulting in an inhibition of weight control thoughts, and causes them to experience goal conflict (Stroebe, Mensink, Aarts, Schut, & Kruglanski, 2008). In this study, when restrained eaters were exposed to a palatable food, namely Spaghetti Bolognese, they might have experienced goal conflict and opted for water as an attempt to resolve the conflict. This might explain why the findings did not support the Boundary Model of Eating Behavior (Herman & Polivy, 1983) (*i.e.*, when participants high in dietary restraint imagined eating large portion sizes, they did not disinhibit and select the HES beverage). However, this goal conflict may have been resolved when the portion of the palatable food was small, allowing for the sweetened beverages to be selected. It is possible that the prospect of eating the small portion led those participants to feel less guilty (Ferrar et al., in preparation) and as though they had calories to spare or to feel accomplished and worthy of a reward (cf. McCaig, Hawkins, & Rogers, 2016).

This experimental evidence complements recent qualitative work which revealed consumers' expectations of using beverages to compensate if they were dissatisfied by the size of a meal (Ferrar, Ferriday, et al., in preparation). While decreasing food portion size encourages the selection of beverages that provide flavour and/or energy, without knowing how much is consumed of these beverages, it cannot be concluded that the energy reduction in the food is negated by the energy increase from the beverage. Therefore, future research should investigate how food portion size affects intake of water, LES beverages, and HES beverages. Further, this tendency for consumers to compensate in order to preserve meal satisfaction should be considered when encouraging portion reduction as a strategy for reducing intake. It would be counterproductive for an individual who is trying to lose weight to compensate for a reduced portion size with a high-energy beverage. While this study did not systematically compare individuals trying to reduce their energy intake from those trying to maintain their energy intake, reducing the food portion size increased the likelihood of selecting the HES beverage in a heterogenous sample in terms of weight, diet status, and dietary restraint. Further, participants with high dietary restraint (compared to participants with low dietary restraint) were overall less likely to choose the HES beverage, but they were more likely to select the HES beverage when the portion size was small.

The results of this study suggest that reducing food portion size would be compensated for with caloric beverages even in individuals actively trying to reduce energy intake. One might expect that dieters especially would be "calorie-conscious" and therefore would not be influenced by the portion reduction manipulation to select the HES beverage. It is possible that participants (including dieters) exercised less restraint because the caloric addition was in the form of a beverage, and not a food, and therefore was less apparently associated with weight gain. Alternatively, depending on how participants selected their ideal portion (*i.e.*, how much they actually eat or what they strive to eat) could play a role. For example, a dieter who selected their "diet" portion as their ideal portion, might have felt that they could afford the additional calories with the smaller portion sizes. As this is speculative, future research is needed to draw firm conclusions.

Much of the research to date has been designed to explore the effects of a beverage preload on intake at a subsequent food test meal (Rogers, Hogenkamp, et al., 2016). However, as outlined in the introduction, beverage consumption does not always occur prior to eating a meal. Therefore, the present study pioneered a methodology with beverage choice as the outcome measure. The authors decided to collect data in a virtual setting as this was the first time the methodology would be employed and virtual measures of ideal food portion size have been shown to predict intake (Wilkinson et al., 2012). However, laboratory studies using the same methodology (which could be modified to measure not only choice, but intake across single or subsequent meals) should be conducted to confirm the effect.

The results of this study suggest that beverages may be used to compensate for the reduction in food during a meal. Further work needs to investigate the significance of this compensation. In this study, reducing the food portion size increased the chances of selecting a caloric beverage, but the amount of caloric beverage consumed was fixed at a single serving (250 ml). Consuming a serving of the HES beverage (103 kcal) with a portion of food reduced by 200 kcal would diminish the degree of caloric reduction, but not completely negate it. However, if participants had ad-libitum access to the beverage, then full compensation, or even overcompensation, may have occurred. Therefore, future work should investigate how beverage intake is affected by food portion size. This is particularly important as research encourages a more conservative portion reduction than employed in the current study. For example, it has been demonstrated that a 25% reduction in food portion size is sufficient to reduce body weight (Rolls, Roe, & Meengs, 2006). On one hand, a subtler reduction is advantageous as consumers are more likely to resist an intervention which is noticeable (Thaler & Sunstein, 2008). On the other hand, it is also easier to inadvertently offset a subtler reduction. For example, reducing the 500 kcal portion size by 25% would reduce energy intake by 125 kcal, but those savings are wasted if a single serving of the HES beverage (103 kcal) is consumed.

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CONFLICT OF INTEREST

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